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# OPERATION OF ORCHARD HEATERS

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# OPERATION OF ORCHARD HEATERS<sup>1, 2</sup>

ROBERT A. KEPNER<sup>3</sup>

## INTRODUCTION

DURING THE WINTERS of 1937-38, 1938-39, and 1939-40, orchard heating was studied comprehensively in the field at the Citrus Experiment Station at Riverside. Though the studies could not cover all types of heaters now in use, they yielded much information on the care and operation of several of the better kinds. Groups of fifty to seventy heaters of each kind were operated, for a combined total of 350 to 400 hours for the types tested. This operating time is equivalent to about fifteen years of average field heating experience.

*Description of Heaters Operated in Field Tests.*—In selecting the kinds of heaters to be tested, the object was to include representatives of the various general types used in orchards. The following heaters were included in these tests:

1. Lazy-flame (Hy-Lo 230A)
2. Jumbo Cone
3. Exchange model, 7-inch stack
4. Kittle
5. Fugit
6. Experimental return-stack-gas heater
7. Experimental coke heater

Lazy-flame heaters are designed to have most of the combustion take place at the top of the stack or above. The Hy-Lo 230A (fig. 1) is one of the more modern heaters of the lazy-flame type. During the winter of 1938-39 these heaters were equipped with the usual type of draft regulators, which must be closed and regulated by hand after lighting (fig. 1). This type of regulator will be referred to here as "standard." During 1939-40, the lazy-flame heaters were equipped with a late-model, automatic, starting-draft control. This, commonly known as an "automatic" regulator, will be so called, though the only automatic feature is

<sup>1</sup> Received for publication August 28, 1940.

<sup>2</sup> This publication is not a report on the phase of the work at Riverside dealing with the relative heating effectiveness of different types of heaters, but presents observations and experiences in the operation of heaters without regard to their effect in the orchard, obtained concurrently with the heating studies. Further heater studies are in progress.

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the closing of the excess draft by means of a thermostat, to terminate the starting period. The design of the burning-rate control differs, however, from that of the standard regulator and, as will be shown later, is an improvement. Figure 2 gives two views of these automatic regulators. At the left in the figure the regulator is open, ready for lighting. This view shows, on the bottom side of the upturned regulator plate, the small box containing the thermostat element that controls the starting draft. Im-

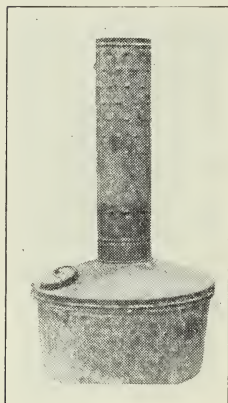


Fig. 1. — Lazy-flame heater with standard regulator. (From Ext. Cir. 111.)

mediately after lighting, the regulator is closed by hand to the position shown at the right. After the heater has burned for 2 or 3 minutes, the thermostat element warms up and causes the regulator plate to drop automatically, which reduces the draft opening to a predetermined operating value.

The Jumbo Cone (fig. 12, *A*) is an example of a combustion-chamber type of heater in which a conically shaped combustion chamber is used. For this type, combustion takes place mainly within the combustion chamber and stack, in contrast to the lazy-flame heaters, in which most of the combustion occurs above the stack.

The 7-inch Exchange stack (fig. 12, *B*) is a combustion-chamber type, but it differs from the Jumbo Cone in having a higher stack and a cylindrical combustion chamber of the same diameter as the stack.

The Kettle (fig. 12, *C*), the only drip-type heater now in general use, differs from the distilling type in that the combustion takes place directly over a shallow, circular fuel trough in the base of the stack, to which fresh oil is fed continuously at the desired rate, either from a pipe line or from a container adjacent to the heater. In the field tests a pipe-line system was used with these heaters, each heater being equipped with a small fuel chamber (fig. 12, *C*, at the right of the stack) in which the oil level was controlled by a float valve, with gravity feed from the chamber to the fuel trough.

The Fugit (fig. 13), a generator-type heater, is operated from a pipe-line system. In this type, the fuel is volatilized while passing through a small evaporation chamber kept hot by the heater flame. The fuel vapor then issues, as a vapor jet, from an orifice, where it burns in a self-induced draft. Burning rate is regulated by a needle valve at each heater.

The return-stack-gas heater, not yet commercially available, is a combustion-chamber type with a return pipe for recirculating part of the

stack gases. It was developed in the Experiment Station laboratories at Davis primarily to answer the demand for a distilling-type heater that will operate for reasonably long periods and over a moderate range of burning rates without objectionable smoke. The portion of stack gases returned to the bowl dilutes the fuel vapors and reduces smokiness. Seventy of these heaters were built at the Experiment Station laboratories at Davis for testing in the field. The return-stack-gas heater is illus-

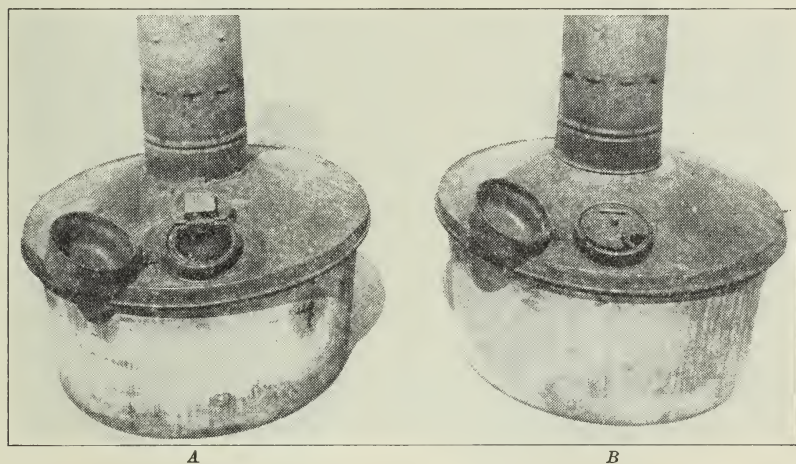


Fig. 2.—Two views of automatic regulator: *A*, open, ready for lighting; *B*, closed after lighting.

trated in figure 3, *B*. The round bowl, cover, regulator, and downdraft tube are of the usual type except that an adapter for the return tube is added to the cover. On the inside of the stack is an elbow connected with the one outside and with its open end extending downward at the stack center.

The experimental coke heater (fig. 3, *A*) used in these field tests was developed by one of the commercial oil companies as a practical, low-cost unit for burning petroleum coke. It has no grate, but merely a solid removable bottom of galvanized iron. Its height is 30 inches, and its top and bottom diameters are 12 inches and 15 inches, respectively. It was constructed this size to produce heat outputs comparable with those of oil-burning orchard heaters.

In these studies lazy-flame heaters with standard regulators, lazy-flame with automatic regulators, return-stack-gas heaters, and coke heaters were burned 60 to 80 hours each, while the heaters of the other types



were operated 20 to 30 hours each. All bowl- or distilling-type heaters used in these tests were equipped with round bowls.

*Reasons for Improving Heater Management.*—In determining the best operating practices for orchard heaters, one should keep in mind

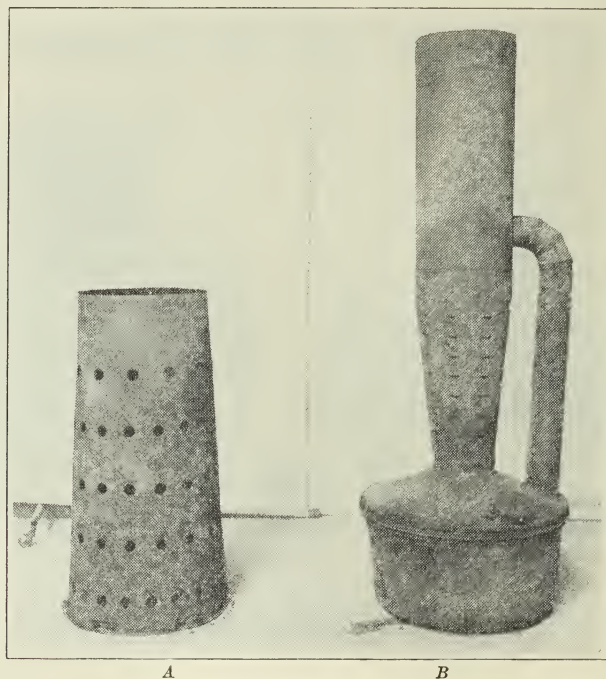


Fig. 3.—Experimental heaters: A, coke heater; B, return-stack-gas heater.

several objectives or purposes for improving heater management :

1. To minimize smoke output
2. To minimize fuel contamination
3. To reduce labor requirements where possible
4. To prolong the life of the heaters
5. To get adequate frost protection with minimum fuel consumption<sup>4</sup>

Assuming that adequate frost protection can be obtained with the heating equipment that a grower has available, the most important problem from a public viewpoint is to eliminate the smoke nuisance.

<sup>4</sup> For any given type of heater, this involves frequent checking of orchard temperatures and regulation of heaters to keep them at the lowest burning rates that will maintain safe temperatures.

## SMOKINESS OF HEATERS

*Previous Tests on Smoke Output of Heaters.*—In 1932 the results of smoke tests on most of the oil-burning orchard heaters then in use were reported in Bulletin 536.<sup>5</sup> The thirty-one heaters tested were classified into four groups according to their smokiness when clean :

1. Five heaters reasonably free from smoke at all usual burning rates under good operating conditions (Jumbo Cone; Kittle; Fugit; Exchange model, 7-inch stack; Hy-Lo, 1929 model).

2. Six heaters that can be operated with little smoke up to burning rates used in moderately cold weather, but which may produce excessive smoke under certain conditions (Baby Cone; Exchange model, 5½-inch stack; National Double Stack; Citrus, high stack; National Junior Louver, 15-inch; Exchange model, 6-inch stack).

3. Seven heaters that are smoky, but which were commercially important in 1932 (Hy-Lo double stack, square bowl; Hy-Lo single short stack, round bowl; Citrus regular; Citrus, 15-inch stack; Hy-Lo double stack, round bowl; Hy-Lo single short stack, square bowl; Citrus Gas Flame).

4. Thirteen heaters that are very smoky but which are mostly of obsolete types.

Additional heaters now on the market would fall in groups 1 and 2. A discussion of the better heaters now available, with the range of their smoke outputs *when clean*, is included in Extension Circular 111.<sup>6</sup>

*Factors Affecting Smokiness.*—The smoke tests referred to above and the heater classification are for heaters operating under optimum conditions—that is, with clean stacks and covers, tight-fitting covers, properly set drafts, clean fuels, and quiet atmospheric conditions. These results, representing the minimum smoke outputs to be expected from these heaters, are lower than those normally found in the field, especially after 1 or 2 nights of heating. The smokiness of heaters is influenced by the following factors:

1. Burning rate. Curves of smokiness vs. burning rate included in the previously mentioned publications, and in figure 4 show definitely that most heaters when clean have a more or less fixed range of burning rates within which the smoke output is a minimum for that particular type of heater. Within this range the smokiness is not greatly affected by the

<sup>5</sup> Schoonover, Warren R., and F. A. Brooks. The smokiness of oil-burning orchard heaters. California Agr. Exp. Sta. Bul. 536:1-67. 1932.

<sup>6</sup> Schoonover, Warren R., F. A. Brooks, and H. B. Walker. Protection of orchards against frost. California Agr. Ext. Cir. 111:1-70. 1939.

burning rate, whereas at rates above this range, smokiness increases rapidly with increase in burning rate. For some heaters this range is narrow, but for the better heaters it is relatively wide. The grower should determine the range of burning rates over which his heaters will burn with the least smoke and should regulate his heaters accordingly. If the smoke

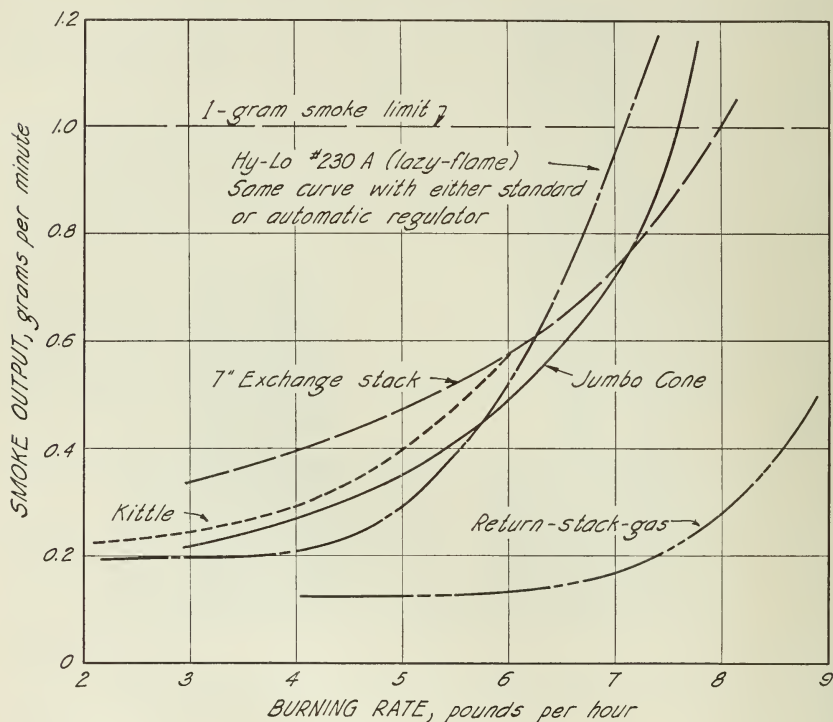


Fig. 4.—Relation of smokiness to burning rate for clean heaters (laboratory tests).

output is to be kept within acceptable limits, the heaters must not be operated at excessive burning rates. Judging from curves of smokiness vs. burning rate for the stack-type heaters studied in the field tests (fig. 4), these heaters all have relatively low smoke outputs over fairly wide ranges of burning rates *when they are clean*. Curves are not shown for the Fugit and petroleum-coke heaters, since their smoke outputs are relatively low for all practical operating rates.

2. Soot accumulation. All oil-burning orchard heaters accumulate considerable soot while burning, some rather rapidly and others at a lower rate. Soot accumulations, particularly in the stacks, contribute directly to heater smokiness. For this reason, stacks and covers should



be cleaned regularly. The frequency of these cleanings will depend upon the type of heater and the rate of burning. In general, high burning rates contribute to rapid soot accumulations, whereas lower rates of burning result in slower soot accumulations.

The simple cylindrical stacks are readily cleaned by running a wire brush through them, but the stack should first be removed in order to avoid pushing the soot deposits into the bowl. Combustion chambers should be taken apart if this is necessary to secure thorough cleaning. While the stacks are off, one should clean the covers by reaching through the stack opening with a scoop or ladle (fig. 5) with which the soot may be scraped off, caught, and removed from the bowl. Downdraft tubes may need cleaning occasionally, particularly if filling of the heaters is done through some opening in the cover other than the one above the draft tube. Smokiness is increased if the slots in the downdraft tube become clogged with soot.

3. Air leakage around covers and regulators. In the handling of heaters between heating seasons, covers, regulators, and stacks are apt to become bent and otherwise damaged so that they do not fit tightly. It is much easier to keep the covers tight-fitting on round bowls than on square bowls; this feature is the chief disadvantage of the latter. Air leakage into the bowl increases soot accumulations and smokiness, besides making it difficult to control the burning rates accurately. Air leakage at the base of the stack, especially with lazy-flame heaters, causes a marked increase in smokiness. Careful handling of heaters, and the discarding or repairing of damaged bowls, covers, and stacks, help to overcome these problems. Heaters left in the field from season to season should give less trouble from this cause than those emptied and hauled out of the orchard every year. The more times a cover is removed, even though not damaged, the greater the tendency for air leakage.

4. Type of oil. Smokiness is not much affected by the usual variations in characteristics of clean oils that are within the range of fuels satisfactory for distilling-type heaters. To be satisfactory for use in orchard heaters,<sup>7</sup> however, a fuel must have certain qualities. The amount of

<sup>7</sup> Bowl- or distilling-type heaters use gas oil generally known as bunker-grade marine Diesel fuel of 27+° A.P.I. (American Petroleum Institute) gravity. The refineries list this grade of oil as Pacific Standard 200, selected for low pour point. (For specification values of this grade of fuel see: Schoonover, Warren R., F. A. Brooks, and H. B. Walker. Protection of orchards against frost. California Agr. Ext. Cir. 111:47. 1939.) The fuel used in the bowl-type heaters during the field tests reported herein had a gravity of 31.3° A.P.I., a 50 per cent distillation temperature of 508° Fahrenheit, and an open crucible self-burning residue of 1.8 per cent (higher than the recommended maximum). The fuel used in the Kittle and Fugit heaters was a kero-distillate of approximately 38° A.P.I. gravity.

residue formed in the bowls is affected somewhat by variations in fuel characteristics. For drip-type heaters the amount of coking in the fuel troughs is increased by the use of poor grades of heater oil. The operation of generator-type heaters is sensitive to oil characteristics.

5. Wind. Stack-type heaters are more smoky in a breeze than during



Fig. 5.—Scraper and brush for cleaning covers and stacks.

calm weather. Since this condition cannot be controlled by the grower, it need not be discussed further.

*Soot Accumulation in Lazy-Flame and Return-Stack-Gas Heaters.*—Extensive observations and measurements of soot accumulation and smokiness, in relation to burning rate and total time interval since cleaning of heaters, were made for the lazy-flame with standard regulator, lazy-flame with automatic regulator, and return-stack-gas heaters. In these tests the heaters were extinguished after every 3 to 4 hours of burning. After each burning period of 3 to 4 hours a group of ten heaters was cleaned, the accumulations of soot being removed separately from

the stacks and covers and measured. A different group was cleaned each time, so that each successive group had burned from 3 to 4 hours longer since cleaning than the previous group.

In figure 6 the relation of the soot accumulations to the burning time is shown separately for stacks and for covers of the lazy-flame heaters. The lazy-flame heaters with automatic regulators were tested at two

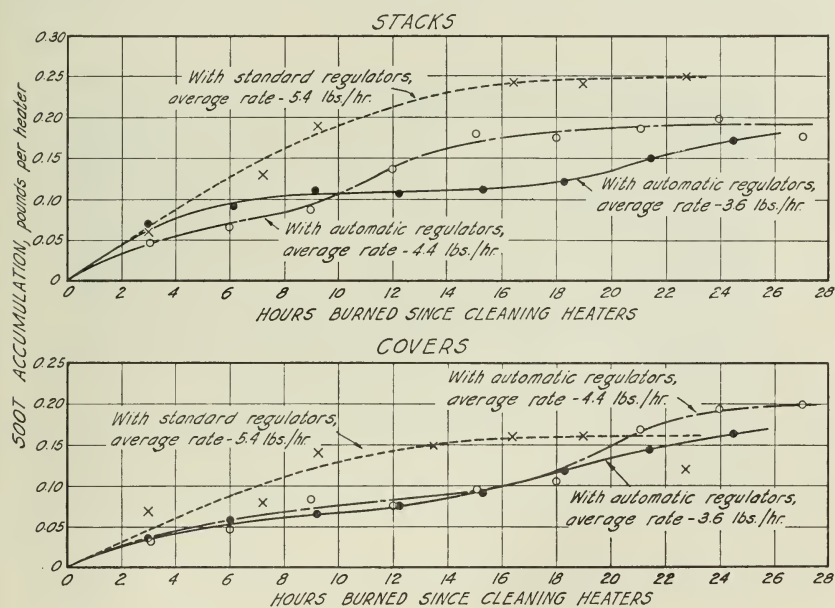


Fig. 6.—Soot accumulation in lazy-flame heaters (ten heaters averaged for each point plotted).

burning rates, and the heaters with the standard regulators were tested at one rate, this being higher than with the automatic regulators.

In the stacks of the lazy-flame heaters with standard regulators, soot accumulated much more rapidly than when the same heaters were with automatic regulators (top of fig. 6). For the two burning rates with the automatic regulators there was little difference in rate of soot accumulation during the first 10 hours, after which the higher burning rate resulted in more rapid accumulation of soot. If the stacks are not cleaned, soot accumulations build up to the maximum amount that will adhere to the stacks, after which the soot is carried away by the stack gases or falls into the bowls as fast as it is formed. After the heaters with standard regulators had burned for 15 to 18 hours, the stacks had accumulated the maximum amount of soot that would adhere to them. After 27 hours

of burning, the soot load in the stacks of the heaters with automatic regulators was still less than the maximum reached when the standard regulators were used.

The covers of the lazy-flame heaters with standard regulators accumulated soot more rapidly than did covers with automatic regulators (bottom of fig. 6). For the two burning rates at which heaters with automatic regulators were tested, there was little difference in the amounts or rates of soot accumulation on the covers. As with the stacks, there is a maximum amount of soot that will cling to the covers. As additional soot is deposited, the flakes or streamers tend to break loose from the supporting cover surface and fall into the oil, which keeps the total amount of soot on the covers about constant. After the heaters with standard regulators had burned for 12 to 15 hours, their covers could hold no additional soot. Covers with automatic regulators accumulated about the same maximum amount of soot as those with standard regulators, but only after a much longer burning period (22 to 25 hours).

The heaters with standard regulators, operated at a higher burning rate than those with automatic regulators, might be expected to accumulate soot somewhat more rapidly. Since, however, there was no great difference in this respect for the two burning rates used for heaters with automatic regulators, very little of the increased rate of soot accumulation for heaters equipped with standard regulators should be attributed to the higher burning rate. The fact that soot accumulations in the stacks and on the covers attain a maximum does not indicate that no more soot is being formed: the rate of formation is undoubtedly higher than during the early stages after cleaning. The additional soot formed either is carried away by the stack gases or falls into the oil and contributes to sludge residue in the bowls. For this reason stacks and covers should be cleaned frequently in order to avoid fuel contamination.

Curves for soot accumulation in the return-stack-gas heaters are not shown; but for the covers, the curve is practically the same as for the lazy-flame heaters with automatic regulators when burning at a rate of 3.6 pounds per hour. The average burning rate for the return-stack-gas heaters was 4.4 pounds per hour. In the stacks, the soot accumulation was much less than with the lazy-flame heaters. The amount of soot in the stacks increased rather uniformly to about 0.05 pound per heater after 16 hours of burning and then, with added burning, remained nearly constant. In the return-stack-gas heaters, only a thin, smooth layer of soot is deposited in the stack above the combustion chamber. Some fluffy carbon is formed in the throat and just below the bottom row of louvers. The return-stack-gas-heater construction may be modified so as to elimi-



nate most of the soot accumulations on the cover ; but the resulting heater costs more, is more difficult to light, and has a narrower range of possible burning rates than the present heater.

*Effect of Soot Accumulation on Smokiness of Heaters.*—During each series of soot measurements for lazy-flame heaters, smoke tests were made at regular intervals on ten heaters, which were cleaned only at the beginning of each series of tests. Figure 7 shows the apparatus used

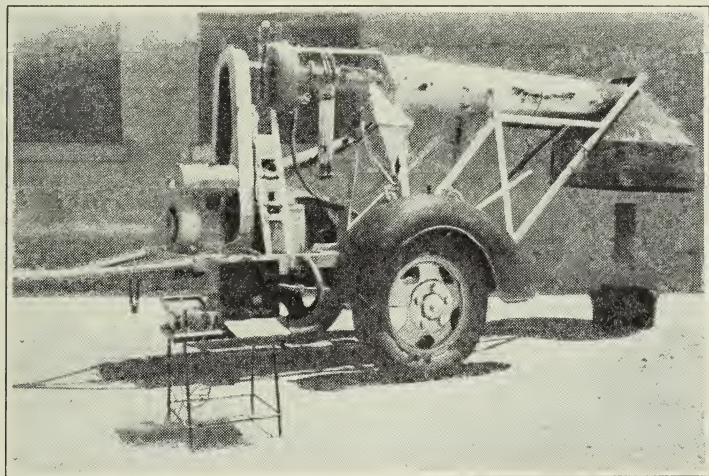


Fig. 7.—Smoke-measuring apparatus, showing heater in position to be tested. All products of combustion from the heater, as well as some outside air, are drawn through the apparatus by a centrifugal blower. The carbon, or soot, from a portion of the gases is collected on a white felt filter pad. The blackness of the felt, a measure of the smokiness of the heater, is determined by a photoelectric cell.

for measuring smokiness. A comparison of the smokiness vs. time of operation since cleaned is included in figure 8 for these heaters with automatic regulators and with standard regulators. As figure 4 indicates, the smoke output of *clean* lazy-flame heaters at any given burning rate is the same with either type of regulator. The difference indicated in figure 8, for the two types of regulators when the heaters were clean, would be expected, since the average rates were 5.4 and 4.4 pounds per hour for the standard regulators and the automatic regulators, respectively. A series of tests for the heaters with automatic regulators at an average rate of 3.6 pounds per hour (curve not included) showed about the same smoke output as at 4.4 pounds per hour, for the first 3 to 4 hours after cleaning. After 25 hours of burning, the smoke output was about 25 per cent less at the lower burning rate.



After the heaters with standard regulators had burned for a few hours, the average smoke output increased rapidly for a time; but eventually, after there was no further increase of soot adhering to the stacks, it became about constant. Apparently the amount of soot clinging to the cover has little effect on the smokiness of heaters. Each point on the curves of figure 8 represents the smokiness of one heater. As the heaters with standard regulators became dirty, the smoke outputs of individual heaters became very erratic, with wide variations within the group tested. Some of the heaters flash back and puff or "blow up" when extin-

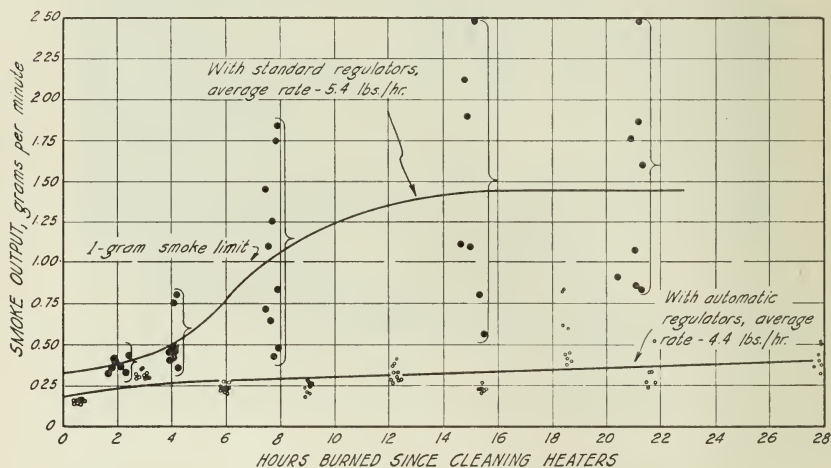


Fig. 8.—Smokiness of lazy-flame heaters as affected by time since cleaning.

guished. In so doing, they partially clean the stacks, which reduces their smoke output. Also, when standard regulators are used there is much variation in burning rates, which causes differences in smokiness, particularly for individual heaters burning at high rates.

In direct contrast, the smokiness of heaters with automatic regulators increased slowly and at a nearly uniform rate; it was still low after 25 to 30 hours of burning. The smoke outputs of individual heaters equipped with automatic regulators were relatively consistent and remained well within the smoke limit of 1 gram per minute.

Whereas lazy-flame heaters equipped with standard regulators had an average smoke output of 1 gram per minute after only 7 hours of burning and 1.5 grams at 15 hours, the heaters with automatic regulators had less than 0.5 gram per minute after 28 hours of burning. The higher burning rate of the heaters with standard regulators accounts for some of the increase in smokiness as compared with the heaters having auto-

matic regulators; but the difference in smokiness after 8 hours' burning was much more than would be explained by the difference in burning rates.

The superiority of automatic regulators over standard regulators on lazy-flame heaters, in regard to soot accumulation and smoke output, may result in part from the automatic control of the starting draft. More probably, however, it is due to improved design of the regulating device. The introduction of air through the smaller regulating holes, the reduction of air leakage around the edges of the regulator, and the more uniform burning rates obtainable with this regulating device are all factors which tend to reduce the soot accumulations and the corresponding smokiness.

Since the return-stack-gas heaters burn relatively free of smoke under most conditions, smoke tests as a function of burning time since cleaning were considered less important for them. Three series of smoke measurements were made, however, on nine heaters, at 1, 16, and 25 hours after cleaning. The heaters were operated at different draft openings in order to get a range of burning rates as a basis for curves of smokiness vs. burning rate (fig. 9). Even heaters that had burned for 25 hours at nearly a gallon an hour (1 gallon = 7.25 pounds) were still well within the smoke limit of 1 gram per minute. At moderate burning rates ( $\frac{1}{2}$  to  $\frac{9}{10}$  gallon per hour) the smoke output of the return-stack-gas heaters does not increase very rapidly with time.

The effect of soot accumulation on the smokiness of Jumbo Cone and Exchange stack heaters was not measured in these tests. Curves of smokiness vs. burning rate for these heaters when clean, and also after a burning period of 20 hours, are included in Bulletin 536.<sup>8</sup> These indicate that the smoke outputs are several times greater after 20 hours of burning than when the heaters are clean.

Soot accumulations in the stack of the Kettle heater are small, and the smoke output does not change appreciably with time. Unless a high-grade fuel is used, however, coking (the formation of hard carbon deposits) takes place in the circular fuel trough of the heater. Unless these deposits are scraped out regularly, the oil will overflow into the base pan and upon ignition will produce large quantities of smoke.

Fugit heaters burn without appreciable smoke as long as the jets are clean and will continue to burn clean until the evaporating chamber fills with coke. Complete vaporization of the oil is then impossible.

The petroleum-coke heaters involve no soot-accumulation problems

<sup>8</sup> Schoonover, Warren R., and F. A. Brooks. The smokiness of oil-burning orchard heaters. California Agr. Exp. Sta. Bul. 536:30, 50. 1932.

and consequently no cleaning. Except for the starting period they burn without appreciable smoke regardless of how long they have been operated.

*Economic Considerations of Smoke Reduction.*—The reduction of smoke has little effect on the heating efficiency of heaters or none, and,

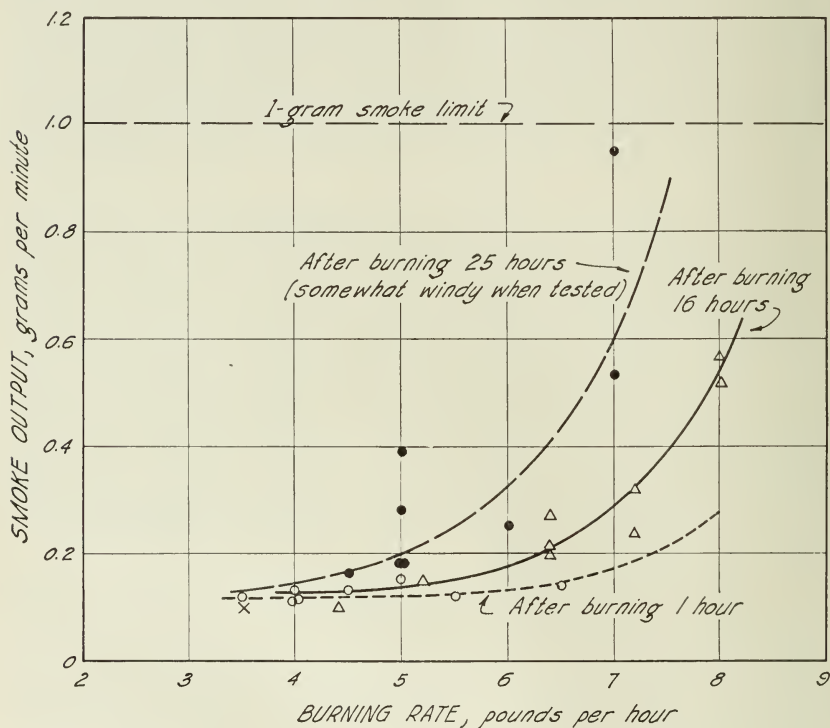


Fig. 9.—Relation of smokiness to burning rate for return-stack-gas heaters at various times after cleaning (field tests).

therefore, cannot be justified on the basis of savings in fuel costs. Since, however, the elimination of the smoke nuisance is essential, each grower must determine the most economical way to accomplish this result. Heaters of obsolete types that cannot be operated without excessive smoke should be replaced, but if a grower's heaters can, by careful management, be kept reasonably free from smoke, he can hardly afford to discard them all immediately and buy new ones. Against the cost of new heaters, however, he must balance the added cost of the careful management required in keeping his old heaters within the smoke-tolerance limits.

## RESIDUE IN DISTILLING-TYPE HEATERS

With the usual fuel oils burned in distilling-type heaters, a sludge residue will form in the bowls in amounts about proportional to the total oil burned; but the quantity depends somewhat upon the characteristics of the fuel. The sludge is made up of the heavier fractions of the oil, along with soot that forms in the bowls and stacks and then falls into the oil. The amount of residue is greatly increased if one allows the soot to fall into the bowls when cleaning stacks and covers. Since the residue decreases the effective fuel capacity of the bowls, it should be disposed of from time to time.

*Residue in Lazy-Flame Heaters.*—Twelve lazy-flame heaters with automatic regulators, which had burned for about 70 hours at an average rate of 4 pounds per hour, were lighted and allowed to burn until they went out of their own accord. Near the end of the burning-out period, the drafts had to be wide open to keep the heaters burning. Eleven out of the group of twelve heaters burned dry; but during the last 5 or 6 hours, the operation of the heaters was unsatisfactory, with much smoke, and large amounts of soot forming in the bowls and stacks. The residue remaining was only 1.5 per cent of the total oil burned; but it was mostly fluffy soot, which nearly half filled the bowls and would have to be removed before the heaters were refilled with oil. Return-stack-gas stacks and covers, placed on twelve other lazy-flame bowls, burned the residue satisfactorily.

No attempt was made to burn out the remaining lazy-flame heaters. Instead, the reclaimable oil was pumped out of the bowls, a filter screen being placed over the intake end of the pump hose. The residue left after pumping out amounted to about 7 per cent of the total oil burned in the lazy-flame heaters with automatic regulators as well as those with standard regulators. This figure is higher than general field observations previously reported,<sup>9</sup> namely, 1 inch or more of sludge in the bowls for every 25 gallons of oil burned, probably because of the relatively high carbon content of the fuel used in these tests.

*Residue in Return-Stack-Gas Heaters.*—After the return-stack-gas heaters had been burned from 45 to 70 hours, they were lighted and allowed to burn until they went out. The draft openings were set at one-third hole (about  $\frac{2}{3}$  gallon per hour burning rate) when lighted and were opened up to one hole during the last part of the burning period to counteract the normal falling off of the burning rate caused by

<sup>9</sup> Schoonover, Warren R., F. A. Brooks, and H. B. Walker. Protection of orchards against frost. California Agr. Ext. Cir. 111:67. 1939.



lower fuel levels. During this burning-out period the heaters did not smoke visibly, and there was no excessive formation of soot.

When the heaters had burned out, the residue remaining was observed and measured. Twenty-eight heaters that had previously burned from 45 to 60 hours at rates of  $5\frac{1}{2}$  to 6 pounds per hour burned completely dry, with only hard flaky carbon left in the bottoms of the bowls. Of thirty other heaters that had burned 70 hours at rates of  $4\frac{1}{2}$  to 6 pounds per hour, about one third failed to burn dry. The cause may have been due partly to water in the bowls. In all the heaters that did burn dry, the carbon residue amounted to only about 0.5 per cent of the total oil burned. The bottoms of the bowls showed no appreciable damage from being burned dry, probably because excessive burning rates were not required.

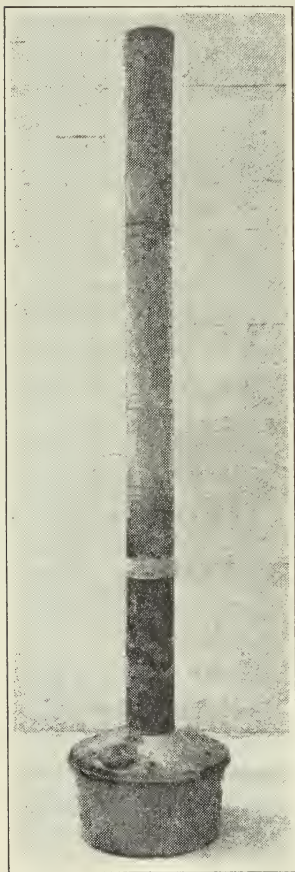


Fig. 10.—Heater for burning sludge residue.

*Disposal of Residue.*—The disposal of the sludge residue formed in bowl-type heaters is a problem. With the return-stack-gas heaters it is practical to get rid of the residue by burning the heaters dry, because burning rates that might damage the bowls are not required. Some of the other distilling types can be burned dry; but this procedure usually requires opening the drafts to obtain high burning rates, and the result is excessive smoke and soot formation and damage to bowls. The residue may be hauled from the orchard and dumped in a dry wash or other suitable place, or burned at some central location.

Another method of disposal would be to accumulate the residue in barrels distributed throughout the orchard and later to burn it in specially constructed heaters during regular heating periods. Heaters which will burn most residues satisfactorily may be built from ordinary heater parts. The principles involved in such a heater are: (1) introduction of air into the bowl at several places so that the flame is not all concentrated at one spot; (2) introduction of this air in the form of jets directed against the surface of the contaminated oil; (3) creation of additional



draft by using a relatively tall stack above a louvered combustion-chamber section.

Such a heater was constructed and tested in the laboratory, using a 6-inch Exchange stack with about 6 feet of straight stack above the louvered section (fig. 10). A round bowl and an ordinary cover equipped with standard regulator and downdraft tube were used. Holes were drilled in the cover and 7 jets were installed. Six of these were spaced at equal intervals around the bowl cover (that is, 60 degrees apart) and 2 inches from the outside edge. The seventh jet was placed between the draft regulator and the stack collar, 1 inch out from the latter (fig. 11). In the original design, tapered jets were used, but subsequent tests indi-

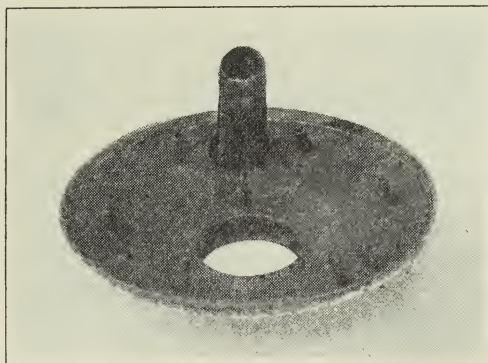


Fig. 11.—The inside of the bowl cover of the residue burner, with the pipe jets and down-draft tube in place.

cated that short lengths of  $\frac{3}{8}$ -inch iron pipe could be substituted for the tapered jets, which simplifies the construction. A 3-inch length of pipe was used for the center jet, and 2-inch lengths were used for the outside jets. By threading one end of each length of pipe and drilling clean  $\frac{5}{8}$ -inch holes in the cover, the pipe jets could be screwed into the holes in the cover (from the underside), the sharp edge of the sheet metal serving as a single thread for the pipe. If clean holes are not obtained, or if the pipe jets should become loose-fitting, lock nuts may be used to fasten the jets to the cover.

If properly regulated, this heater will burn residue without excessive smoke, although the burning rate is higher than normal (1 to 1½ gallons per hour). If the burning rate is much below 1 gallon per hour, the heater does not "louver" properly, and may not burn dry. Rates in excess of 1½ gallons per hour cause objectionable smoke and result in high stack temperatures with rapid deterioration, particularly of the lou-

vered portion. These heaters should be located where they may be readily observed, since occasional regulation is necessary to keep them burning properly. Normal operation is with the draft regulator completely closed and all jets open, although the regulation depends upon the quality of the residue and the fuel level in the bowl. The draft may be decreased from the normal amount by plugging one or more of the outside jets with metal plugs such as  $\frac{3}{8}$ -inch machine bolts, and it may be increased by opening the draft regulator.

Since the primary purpose of these heaters is the disposal of residue, they should be burned dry each time they are lighted. The residue burners would consume approximately twice as much fuel as the ordinary heaters since they burn at a higher rate and should burn dry each time. Hence, although the amount of residue produced by ordinary bowl-type heaters is from 5 to 10 per cent of the total quantity of fuel oil burned, the number of residue burners need not be greater than 3 to 5 per cent of the total number of heaters operated.

### OPERATION OF OIL-BURNING HEATERS

*Lazy-Flame.*—Lazy-flame heaters are harder to light than many of the other types because the flame tends to lift from the top of the stack and not keep the stack vapors ignited. Heaters with automatic regulators are a little better in this respect than those with standard regulators, because the starting draft is less strong. In lighting heaters equipped with automatic regulators, the follow-up man is eliminated, so that one third to one half of the usual lighting labor is saved. These regulators are so constructed as to close 2 to 3 minutes after lighting. Ordinarily, very little trouble was experienced with regulators' failing to close automatically, except on one occasion, when the heaters were only about half full of oil when lighted. Under the latter conditions about 10 per cent failed to close automatically, and the thermostats never did get hot enough to allow closing by hand. Since, however, heaters are normally kept filled, this condition should not occur under good management.

As previously mentioned, the regulating device of the automatic regulator surpasses the ordinary type; there is less air leakage around the edges of the regulator plate, and the draft holes are smaller, which permits more accurate adjustment and more uniform burning rates. With the automatic regulators the rates of individual heaters for any one night varied only about 15 per cent from the average, as compared with variations up to 50 per cent when the standard regulators were used. The automatic regulators give a maximum rate of  $\frac{2}{3}$  to  $\frac{3}{4}$  gallon per hour when open the full three holes, though provision is made for raising the

regulator plate slightly to give higher rates for emergencies. This value of  $\frac{3}{4}$  gallon per hour is the recommended maximum burning rate for these heaters regardless of the type of regulator used.

When equipped with standard regulators, the lazy-flame heaters tend to flash back and blow off the stack caps and occasionally the bowl covers after they have supposedly been extinguished. With the automatic regulator, the cap over the regulator parts fits tightly, so that lazy-flame heaters with tight bowl covers may be extinguished without closing the stack caps and without the usual tendency to flash back. Closing the stack caps, even for the heaters with automatic regulators, results in occasional flashing back.

Lazy-flame heaters of the type included in these tests are relatively low-priced, and will burn without excessive smoke if operated properly. They are easy to clean, but need cleaning frequently, particularly when equipped with standard regulators. To keep such heaters within the smoke-tolerance limits one must clean them after every 8 to 10 hours of burning. With automatic regulators, the heaters may be operated 20 to 25 hours without cleaning.

Since the automatic regulators were new at the beginning of the one season during which they were used, field observation did not include information on their life or on the functioning of the automatic starting-draft control after they had been used for several years. The superiority of the draft-regulating device over the standard regulator will not diminish because of depreciation, irrespective of whether or not the automatic starting-draft control continues to function satisfactorily.

*Return-Stack Gas.*—These heaters (fig. 3, *B*) are easy to light; but when they are equipped with standard regulators, the stack caps must fit snugly. Otherwise, they are likely to be blown off by flashing back after the heaters have supposedly been extinguished. The return-stack-gas heaters should be regulated as soon as possible after lighting (1 to 3 minutes is preferable); otherwise the stacks get extremely hot, and there is excessive smoke. Unlike other bowl types, the return-stack-gas heaters have a minimum rate at which they burn when the draft is entirely closed. With standard regulators, which have some air leakage when closed, the minimum rate is slightly above  $\frac{1}{2}$  gallon per hour.

Because of the larger number of parts, the handling and assembly of these heaters in the field is more difficult than for many bowl-type heaters. In the field tests of the experimental heaters some trouble was had with the inside elbows' falling off into the bowl during operation. In commercial design it is proposed to fasten the inside elbow to the stack, which would eliminate this trouble and also facilitate assembly and handling.

Two of the return-stack-gas heaters were equipped with automatic regulators of the type used on the lazy-flame heaters but set to close more quickly—that is, about 1 minute after lighting. The automatic control of the starting draft, by reducing the initial draft rate, reduced the smoke output during the starting period and kept the stacks at lower temperatures. Soot tended to collect on the thermostat box and, unless scraped off before lighting, acted as an insulator and thus delayed the action of the thermostat in terminating the starting period. The tight cap used over the parts of the automatic regulator eliminates flashing back after the heaters are extinguished and reduces the minimum burning rate to about  $\frac{1}{10}$  gallon per hour. As with the lazy-flame heaters, the improved regulating device allows more accurate control of burning rates. The effects of using automatic regulators on other combustion-chamber-type heaters with tight bowl covers would probably be similar to those described above.

The return-stack-gas heater, if produced commercially, would be in a price range with the Jumbo Cone heater. The rate of depreciation would be less than for the Jumbo Cone but greater than for lazy-flame types. The experimental heaters were built with stacks and combustion chambers of 24-gauge galvanized iron, and two 28-gauge galvanized-iron elbows were used on the recirculating system of each heater. The stacks and combustion chambers of heaters that had burned for 60 to 70 hours at rates from  $\frac{1}{2}$  to  $\frac{3}{4}$  gallon per hour showed very little depreciation. The combustion chambers and lower 6 inches of the stacks of heaters operated at higher burning rates were oxidized to some extent, but were still in good condition. The use of galvanized-iron elbows inside the stacks is unsatisfactory because of their relatively short life, especially at high burning rates. The galvanized-iron outside elbows were in good condition after 60 to 70 hours of operation, but the inside elbows should be made of some heat-resistant material such as cast iron or chromium steel.

One of the most important features of the return-stack-gas heater, as compared with other bowl-type heaters, is its ability to burn the ordinary 27+ heater oil with little smoke over a relatively wide range of burning rates (fig. 4). In general practice the return-stack-gas heaters should be burned at rates below  $\frac{9}{10}$  gallon per hour. Rates of 1 gallon per hour may be obtained without excessive smoke; but at these higher rates soot accumulates on the covers more rapidly, and the depreciation of the stacks is higher. Although these heaters will burn for long periods without becoming smoky, the covers and throats of the stacks should be cleaned regularly—that is, after 25 to 30 hours of burning—to keep soot



from contaminating the oil. It would seem good practice to burn such heaters dry after every 50 to 75 hours of use, to avoid accumulations of undesirable residue in the bowls.

*Jumbo Cone.*—Jumbo Cone heaters (fig. 12, *A*) are easy to light, but difficult to keep regulated. The draft setting is sensitive, and the burning rates keep changing after the draft controls have been set, so that frequent regulation is required. As with the return-stack-gas heaters,

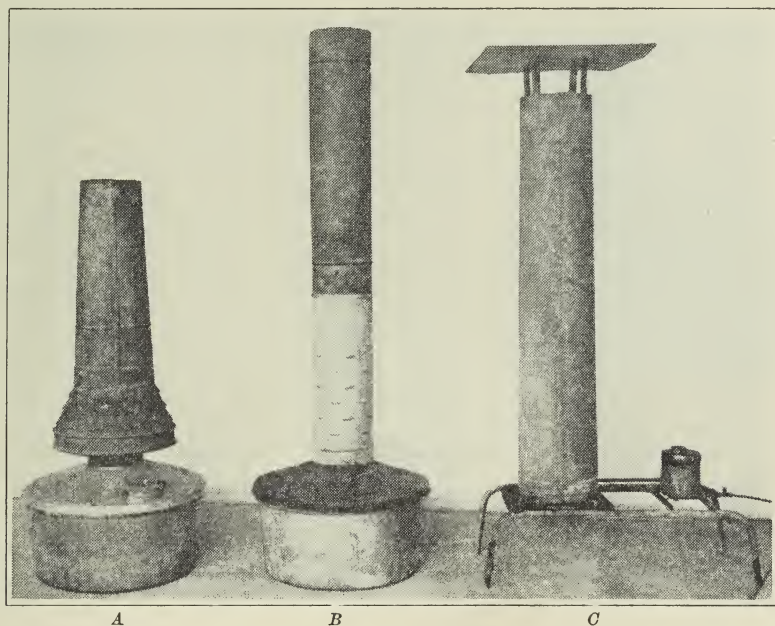


Fig. 12.—*A*, Jumbo Cone heater; *B*, 7-inch Exchange model; *C*, Kettle with float regulator, for use with pipe-line system.

the Jumbo Cones should be regulated as soon as possible after lighting. This is generally true for all combustion-chamber or hot-stack-type heaters. The Jumbo Cone does not burn satisfactorily at rates much below  $\frac{1}{2}$  gallon per hour. From the smoke-output standpoint it is, if cleaned frequently, reasonably satisfactory over a fairly wide range of burning rates. The burning rate must not be allowed to exceed the capacity of the combustion chamber, or excessive smoke will result. This limit is about 1 gallon per hour. Cleaning is more difficult than for heaters with straight stacks, because the combustion chamber must be taken apart for thorough cleaning.

*Exchange Model, 7-inch Stack.*—The performance of the 7-inch Ex-



change stacks (fig. 12, *B*) is more erratic than for stacks with conical combustion chambers such as the Jumbo Cone. Otherwise, most of the discussion for the Jumbo Cone heater applies to this heater. Like the Jumbo Cone, the Exchange stack, if cleaned frequently, has a fairly wide range of satisfactory burning rates; but it is easier to clean. The Exchange stacks deteriorate rapidly, especially at the higher burning rates.

*Kettle*.—As long as the fuel trough of the Kettle heater (fig. 12, *C*) is kept level and free from coke, the heater

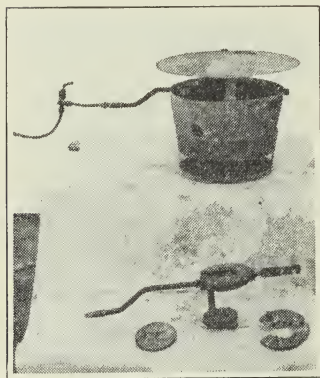


Fig. 13.—Fugit heater (1937 model) with generator parts shown below. (From Ext. Cir. 111.)

operates satisfactorily at burning rates below  $\frac{3}{4}$  gallon per hour. If the rate is above this limit, the oil is likely to overflow the trough and spill into the base pan, where it eventually ignites and produces much smoke. Unless a good grade of fuel is used, the trough soon fills with carbon, and overflowing is likely to occur at rates lower than  $\frac{3}{4}$  gallon per hour. This carbon residue must be scraped from the trough at intervals depending on the rate of burning and quality of fuel. With these heaters there is no problem of accumulation of sludge residue or contamination of the fuel supply with heavy ends (pour-back oil).

Kettle heaters are among the easiest to light; and since they are extinguished simply by shutting off of the fuel supply, no flashing back occurs. When they are used in a pipe-line system, it is hard to find a satisfactory method of regulating the oil flow to the heaters. Ordinary needle valves are unsatisfactory: they are rather sensitive and tend to clog. The float-valve regulating devices used in these field studies gave trouble because of sticking of floats, dirt in the float valves, and other difficulties that would cause the float chambers to overflow on the ground. This fuel upon ignition would often generate enough heat to melt the solder in the joints of the chamber, and thus ruin the device. The Kettle heater, when used with an individual oil container comparable in size with the bowl of a distilling-type heater is equipped with a satisfactory regulating device.

*Fugit*.—The outstanding advantages of the Fugit heater (fig. 13) are low smoke output, elimination of the task of hauling oil and filling individual heaters, and the absence of pour-back problems. These heaters do not, however, operate satisfactorily with burning rates much below 1

gallon per hour, which is higher than should be used for the best utilization of heat in the orchard. They tend to waste fuel, especially on nights that are only moderately cold. The cost of installation per heater being higher, there is a tendency to install too few per acre and to burn them at relatively high rates, which results in an uneven distribution of heat in the orchard.

Generating heaters require a comparatively high grade of orchard-heating fuel (kero-distillate). Even then there is trouble because the jets may plug with carbon and because the evaporating chambers eventually coke so badly on the inside that they must be discarded. The needle valves for regulating burning rates tend to plug with dirt and scale from the pipe lines and with other foreign matter unless a good filter—for example, one of lamb's wool—is installed ahead of each valve. Even with these precautions one must check the heaters often, during the night, to maintain a uniform burning rate.

To keep pipe lines full and to have oil immediately available at each heater when lighting, one should extinguish the Fugits by closing the valve at each heater. If the heaters are extinguished by closing only the main valve for the system or for a lateral, the oil in the pipe lines will slowly drain to the low heaters and overflow on the ground.

### COKE HEATERS

In the past, less than 10 per cent of the orchard heating has been done with heaters burning petroleum coke, coke briquettes, or other solid fuels, largely because of the unavailability and the high cost of these fuels as compared with oil. In 1939, however, petroleum coke (a by-product of oil refining) was made available in quantities ample for orchard-heating needs, at a price (\$4.50 a ton, in bulk, at the refinery) comparable with that paid for ordinary heater oil. Since this makes the use of coke for heating orchards more practical from the cost standpoint, the operation of coke heaters was extensively studied at Riverside during the winter of 1939-40. A total of about 20 tons of petroleum coke (size 1 to 4 inches) was burned during field tests of the experimental heaters.

Most of the solid-fuel heaters on the market have burning rates ranging from 2 to 5 pounds per hour, which is equivalent in heat output to only  $\frac{2}{10}$  to  $\frac{1}{2}$  gallon of fuel oil per hour. The experimental heaters tested (fig. 3, A) were built of a larger size to provide a heat output comparable with that of an oil heater burning at a normal rate ( $\frac{1}{2}$  to  $\frac{3}{4}$  gallon per hour). In the field these heaters were filled to the lower row of holes with earth to protect the sheet-metal bottom from heat.

*Lighting and Burning-Rate Characteristics.*—One objection to solid-fuel heaters, often advanced by growers, is that they are hard to light and slow in getting started. The usual method of starting is to add oil-soaked wood kindling at the top of the heater, though other kindling materials are sometimes used. Then the heaters are lighted by pouring burning torch fuel on top of this kindling. A mixture containing 50 per cent heater oil or crankcase drainings and 50 per cent gasoline is a better torch fuel for coke heaters than is the customary mixture of kerosene and gasoline. According to tests conducted by one of the commercial oil companies the optimum amount of oil-soaked wood kindling is from  $1\frac{1}{2}$  to 2 pounds per heater. If the kindling has been in the heaters for a considerable length of time, a small amount of oil should be poured over it before lighting.

The dotted curve of burning rate vs. time, shown in figure 14, is characteristic for the experimental coke heaters when started with oil-soaked wood; and it bears out the growers' criticism that coke heaters are slow in coming up to their normal burning rate. The rate is fairly high during the first 15 minutes, while the kindling is burning; but then it drops, and upwards of an hour is required for the heater to come up to its normal burning rate.

To remedy this fault, various lighting methods were studied. By pouring ordinary 27+ heater oil over the coke before lighting (using no other kindling material), one can control the initial burning rates by the amount of oil added. Also, if desirable, one can add this oil several days before lighting, with good results. The solid curve in figure 14 shows a typical burning-rate curve when 1.5 quarts of oil was added to about 40 pounds of coke 20 hours before the heaters were actually lighted. The burning rate starts at a fairly high value, drops only to about 7 pounds per hour, slowly rises to a peak of about 8 pounds per hour, and then gradually drops off as the supply of coke becomes exhausted. For 40 pounds of coke the burning rate remains between 7 and 8 pounds per hour for about 4 hours—a rate equivalent to burning about  $\frac{3}{4}$  gallon of orchard-heater oil per hour.

Except for the starting period of an hour or less, all the burning-rate curves for coke heaters *started with oil* have about the same shape with respect to the 8-pound peak, regardless of the amount of oil used or the initial amount of coke. For smaller amounts of coke, the peak and subsequent falling off of the rate occur sooner after lighting; but the peak value is about the same for different amounts of coke, provided the heaters are not filled above the top row of holes. The amount of coke in the heater has little effect on the amount of starting oil required. The use

of 1.5 quarts per heater gives the most nearly uniform burning rate. One may increase the initial burning rate to as much as 12 to 14 pounds per hour by using 1.8 quarts of oil, whereas if only 1.3 quarts are used the initial rates will be a little less than that shown by the solid curve in figure 14.

The heaters can be lighted as much as a week after adding the starting oil, but the lighting is then more difficult and less certain. If the starting oil has for some reason been added one or two weeks before lighting of the heaters, 0.5 quart more oil per heater should be added just before

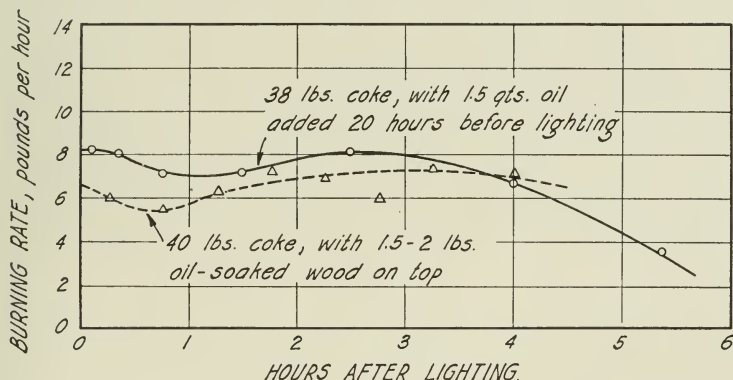


Fig. 14.—Variation of burning rate with time after lighting, for experimental coke heaters (six heaters averaged for each curve).

starting, to make them easy to light. If only one application of starting oil is to be used, it should be applied not more than 1 or 2 days before lighting. Coke heaters light most easily, and the initial rates tend to be a little higher, if the entire amount of starting oil is added within a few hours of the lighting time.

When oil is used for starting, the rates of individual heaters vary considerably during the first  $\frac{1}{2}$  hour because of variations in the size of coke, distribution of oil on the coke, amount of lighting fluid used, and the like; but except for this starting period the rates are relatively consistent. More smoke is produced by oil used alone for starting than by the oil-soaked wood kindling. On the other hand, the smoke output of oil-started heaters at the time of lighting is only about  $\frac{3}{4}$  gram per minute, or less. At the end of 15 minutes the smoke output is not over  $\frac{1}{4}$  gram per minute; and 30 minutes after lighting, it is negligible. The cost per heater of kindling materials for starting with oil and with oil-soaked wood kindling is about the same, but the actual heating value per heater of the oil used is about four times that of the kindling.



Fine coke or dust in a coke heater reduces the starting rate considerably. Conceivably, if the coke remains in the heaters for several years before being used, it may disintegrate somewhat and settle into a relatively compact mass. Time limitations of these field studies did not, however, permit tests of this nature. If this difficulty should occur, the coke will not burn satisfactorily because of reduced draft and air spaces. Coke in this condition should be emptied from the heaters and screened at the beginning of the season.

Covers for coke heaters are necessary to protect the fuel from rain. Wet wood kindling will not ignite readily until it has dried, and then it burns at a reduced rate. If the coke gets wet after starting oil has been added, it will not ignite without the use of oil-soaked wood kindling. If fresh oil alone is added to wet coke, the charge will not ignite. Coke exposed to rain a few hours before lighting will burn satisfactorily if fresh wood kindling is used, but at a rate of about 1 pound per hour lower than dry coke started with wood kindling. Coke stored in the field dries out within a few days after a rain, provided it is not stored in too large a pile.

*Control of Length of Burning Period.*—One drawback to the use of coke heaters is the lack of any practical means of extinguishing them. Their use is therefore impractical in localities where orchard-temperature conditions are unsteady and if the temperature may rise quickly above the danger point soon after lighting so that heaters are no longer needed. In localities where temperatures are more steady and where, once the heaters are lighted, they will probably be needed for several hours or until sunrise, the heating period can be estimated closely. In this case the problem is to adjust the effective burning period of the coke to approximate the length of time heating is required. When heat is no longer needed, one may dump the burning coke on the ground, where it will soon stop burning, with a resultant saving of possibly 75 per cent of the excess coke. The salvaging of this coke involves, however, considerable labor; and the residue is difficult to burn at satisfactory rates when put back into the heaters.

The alternative to extinguishing the heaters is to use partial initial charges, sufficient for short heating periods, and then (if necessary) refuel the heaters while they are burning. Probably the standard initial charge in heaters of the size tested should be about 25 pounds, which gives a good burning rate for about 3 hours. If a cold night is predicted a day in advance, more coke may be added the day before lighting. Otherwise, if heat is needed for longer than 3 hours, more coke must be added while the heaters are burning. Not more than 7 to 8 pounds (1 hour's supply)



should be added at one time; and this should be done while at least 10 to 15 pounds of burning coke still remains in the heater. If larger amounts are added, the burning rates may be depressed to as low as 3 pounds per hour for  $\frac{1}{2}$  hour or more after refueling. The curve of burning rate vs. time in figure 15 shows that when one follows the recommended refueling procedure, the burning-rate depression is small and lasts only a short time. In refueling, the dust and fine coke sometimes found in the bottom of a sack should not be used, for they will reduce the draft and lower the burning rate.

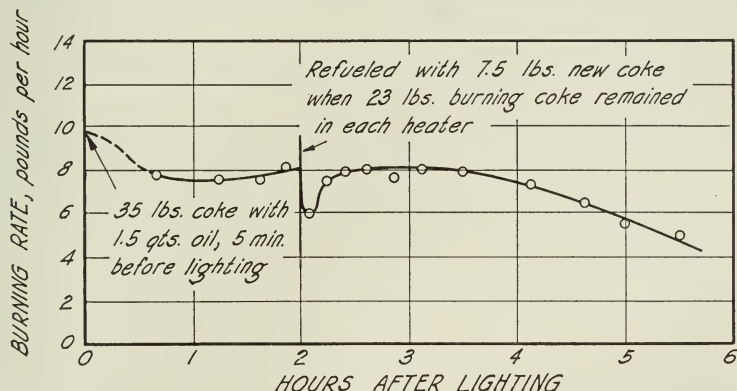


Fig. 15.—Effect on burning rate of experimental coke heaters when refueled with 1 hour's supply of new coke (average of three heaters).

**Fuel Losses.**—When coke is used as a fuel for heating orchards, several types of loss or waste occur. In heaters without grates, some unburned residue is always left in each heater after burning; this takes a conical shape. After the heaters have been burned two or three times, the amount of residue remains fairly constant, approximating 6 to 7 pounds per heater. As the pieces of coke in a heater burn and become smaller than the draft holes in the side of the heater, some coke dribbles through these holes and is lost. This loss amounts to about 2 per cent of the total coke burned. As the supply of burning coke diminishes, the burning rate eventually becomes too low to have practical value in protecting an orchard. The coke burned at the low rates at the end of the burning period is therefore mostly wasted. If the minimum effective rate is taken as 5 pounds per hour (equivalent to  $\frac{1}{2}$  gallon of oil), this waste will be 6 to 8 pounds per heater. In practice the grower would sometimes overestimate the required heating period by  $\frac{1}{2}$  hour or more, which increases the waste about 5 pounds per heater.

The principal losses, then, are (1) a loss of about 6 to 7 pounds per

heater for every time the heaters are emptied or taken out of the orchard, which may occur once a season or less frequently if the heaters are not removed from the orchard each year; (2) a variable loss from dribbling, about 2 per cent of the total quantity of coke burned; and (3) ineffective use of burned coke, which may be 6 to 12 pounds per heater for each time the heaters are burned.

*Storage and Handling of Coke.*—The best practice for storing the coke and handling it in the field can be determined only from general orchard experience, and will be largely controlled by individual preference and circumstances. The coke might be piled in bulk in the tree rows in low board enclosures; it might be stored in one large pile, and a season's supply kept in the field in sacks or other containers; or it might be hauled to the field in bulk, and the heaters filled from the truck or wagon.

*Labor Requirements.*—The labor requirements for filling coke heaters from sacks stacked in the field are about the same as for filling oil heaters, or perhaps a little greater. Filling coke heaters is a dusty, dirty, and disagreeable job. But whereas a few operators get dirtier with coke than with oil, the entire surrounding community benefits from the resultant absence of smoke. The time required for lighting coke heaters is about the same as for lighting lazy-flame heaters with automatic regulators. Kindling the heaters before lighting takes about twice as long as the lighting, the labor requirement being slightly higher for applying oil to the coke than for adding oil-soaked wood kindling. In contrast to oil heaters, the coke heaters require no labor for cleaning, no labor for regulation unless they are refueled while burning, and ordinarily no labor for extinguishing.

*Depreciation of Heaters.*—Coke heaters are rather short-lived as compared with most oil-burning types. Those used in the tests were made of 22-gauge galvanized iron, and their life probably would not be more than 150 hours, or about seven to eight years of use under average heating conditions. Since the top half of the heater does not get very hot, the life of the heater could be increased by so constructing it that either end could be used as the bottom. The high rate of depreciation is offset largely by the low first cost.

*Commercial Solid-Fuel Heaters.*—Of the various solid-fuel heaters on the market, the majority are small and have low burning rates, so that a larger number per acre is required than for oil-burning heaters. With some commercial heaters the burning rate fluctuates considerably with time—an undesirable feature. Although the preceding discussion pertains specifically to the experimental coke heaters, much of the information may be applied to commercial solid-fuel heaters.

## SUMMARY AND RECOMMENDATIONS

Although the operation of only a few types of heaters could be studied in detail, much of the discussion may be applied to the general operation of orchard heaters.

The following practices tend to minimize smoke output :

1. Keep burning rates within proper operating range for least smoke for the type of heater used.
2. Clean stacks and covers regularly, at least after every 20 to 30 hours of normal burning.
3. Use tight-fitting covers, and keep them tight-fitting by careful handling.
4. Regulate heaters as soon as possible after lighting, and keep them properly regulated by frequent inspection.

To reduce difficulties of residue in bowl-type heaters :

1. Empty bowls after every 50 to 75 hours of burning, either by dumping the residue or burning it out.
2. Remove soot from heaters when cleaning stacks and covers without allowing it to fall into the bowls.
3. Keep pour-back oil separate from new oil.

New heaters should be burned several hours during the daytime before they are needed at night ; the lazy-flame types in particular light more easily after they have a little soot in the stacks.

The automatic regulators used in these field tests have certain definite advantages over the standard ones. The draft-regulating device surpasses the ordinary type of regulator by giving more accurate control of the burning rate, besides reducing soot accumulations and smoke output when used on round-bowl lazy-flame heaters. There is no reason to believe that similar results would not be obtained if these devices were used on square-bowl lazy-flame heaters with tight covers. Most bowl-type heaters would be improved by the more accurate control of burning rate possible with these regulators. The automatic, starting-draft control was found satisfactory for the lazy-flame heaters, although it is not known how well these devices might function after several years of use.

With careful management, coke heaters have certain advantages in localities where temperatures are relatively steady with heating periods of reasonable length on nights when firing is necessary. Because of the lack of any satisfactory method of extinguishing coke heaters, to use them exclusively is impractical wherever conditions are often unsteady with large and frequent fluctuations of temperature. One might advantageously alternate coke and oil heaters in an orchard, using the oil heaters

for small heat demands and using the coke heaters or both under more severe conditions. The chief advantages of coke heaters are lower investment costs and the elimination of the smoke nuisance.